Given

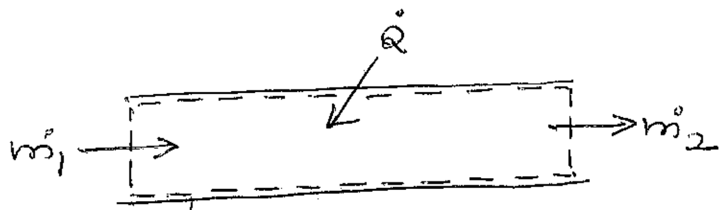
Flow of R-134a through an evaporator tube

Find

(a) Diameter (cm) of the evaporator tube

(b) Velocity ($\frac{m}{s}$) of R-134a at the exit

System



$T_1 = -4°C$
$x_1 = 0.2$
$\mathbb{V}_1 = 7\ \frac{m}{s}$

Flow of R-134a through evaporator is the system

$T_2 = -4°C$
sat. vapor

Assumptions

- Open system
- Steady state, steady flow
- 1-D, uniform flow

Basic Equations

$$\cancel{\frac{dm}{dt}}\Big|_{system}^{\,0} = \cancel{\sum_{in}} \dot{m}_{in} - \cancel{\sum_{out}} \dot{m}_{out}$$

Solution

(a) Mass flow rate of R-134a at the inlet:

$$\dot{m}_1 = \rho_1 A_1 \mathbb{V}_1 = \frac{A_1 \mathbb{V}_1}{v_1}$$

State 1 $T_1 = -4°C$, $x_1 = 0.2$

$$v_1 = v_f(T_1) + x_1\left(v_g(T_1) - v_f(T_1)\right)$$

$$= 0.00076460\ \frac{m^3}{kg} + 0.2 * (0.079866 - 0.00076460)\ \frac{m^3}{kg}$$

$$= 0.016585\ \frac{m^3}{kg}$$

Area at the inlet: $A_1 = \dfrac{\dot{m}_1 v_1}{\mathbb{V}_1} = \dfrac{0.1\ \frac{kg}{s} * 0.016585\ \frac{m^3}{kg}}{7\ \frac{m}{s}}$

$$A_1 = 0.000237\ m^2 = \frac{\pi}{4} D_1^2$$

Diameter of the evaporator tube: $D_1 = 0.0174\ m$

$$\boxed{D_1 = 1.74\ cm}$$

(b) Mass flow rate of R-134a at the exit:

$$\dot{m}_2 = \rho_2 A_2 \forall_2 = \frac{A_2 \forall_2}{v_2}$$

State 2 $T_2 = -4°C$, sat. vapor

$$v_2 = v_g(T_2) = 0.079866 \frac{m^3}{kg}$$

Velocity of R-134a at the exit: $\forall_2 = \frac{\dot{m}_2 v_2}{A_2}$

Mass balance: $0 = \dot{m}_1 - \dot{m}_2 \Rightarrow \dot{m}_2 = \dot{m}_1 = 0.1 \frac{kg}{s}$

$$\forall_2 = \frac{0.1 \frac{\cancel{kg}}{s} * 0.079866 \frac{m^{\cancel{3}}}{\cancel{kg}}}{0.000237 \cancel{m^2}} \Rightarrow \boxed{\forall_2 = 33.7 \frac{m}{s}}$$

Given

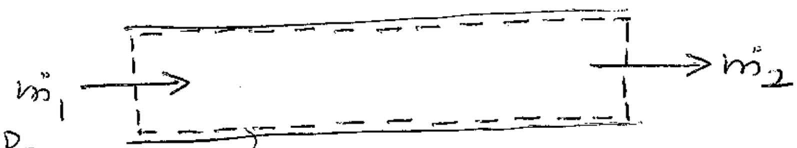
Flow of air through a pipe

Find

(a) Velocity ($\frac{m}{s}$) of air at the exit

(b) Absolute pressure (kPa) of air at the exit

System



$T_2 = 305\ K$

$P_1 = 900\ kPa$
$T_1 = 320\ K$
$V_1 = 30\ \frac{m}{s}$

Flow of air through the pipe is the system

Assumptions

- Open system
- Steady state, steady flow
- 1-D, uniform flow
- Air behaves as an ideal gas
- Insulated : $\dot{Q} = 0$
- Rigid : $\dot{W} = 0$
- Ignore change in PE

Basic Equations

$$\cancel{\frac{dm}{dt}}\Big|_{system} = \sum_{in} \dot{m}_{in} - \sum_{out} \dot{m}_{out}$$

$$\cancel{\frac{dE}{dt}}\Big|_{system}^{0} = \sum_{in} \dot{m}_{in}(h + ke + \cancel{pe})_{in} - \sum_{out} \dot{m}_{out}(h + ke + \cancel{pe})_{out} + \cancel{\dot{Q}} - \cancel{\dot{W}}$$

Solution

(a) Mass balance : $0 = \dot{m}_1 - \dot{m}_2 \Rightarrow \dot{m}_1 = \dot{m}_2$

Energy balance : $0 = \cancel{\dot{m}_1}\left(h_1 + \frac{V_1^2}{2}\right) - \cancel{\dot{m}_2}\left(h_2 + \frac{V_2^2}{2}\right) + 0 - 0$

$$\frac{V_2^2}{2} = (h_1 - h_2) + \frac{V_1^2}{2} = C_p(T_1 - T_2) + \frac{V_1^2}{2}$$

$$= 1.005\ \frac{kJ}{kg-\cancel{K}} * (320 - 305)\cancel{K} + \frac{(30)^2}{2 \times 1000}\ \frac{kJ}{kg}$$

$$\frac{V_2^2}{2} = 15.525\ \frac{kJ}{kg} = 15{,}525\ \frac{m^2}{s^2}$$

Velocity of air at the exit : $\boxed{V_2 = 176.2\ \frac{m}{s}}$

(b) $\dot{m}_1 = \dot{m}_2 \Rightarrow \rho_1 A_1 V_1 = \rho_2 A_2 V_2 \Rightarrow \frac{\cancel{A_1} V_1}{v_1} = \frac{\cancel{A_2} V_2}{v_2}$

Ideal gas equation: $Pv = R_{air} T$

$$\frac{V_1}{\frac{\cancel{R_{air}} T_1}{P_1}} = \frac{V_2}{\frac{\cancel{R_{air}} T_2}{P_2}}$$

Absolute pressure of air at the exit:

$$P_2 = P_1 * \frac{V_1}{V_2} * \frac{T_2}{T_1} = 900\,kPa * \frac{30\,\frac{m}{s}}{176.2\,\frac{m}{s}} * \frac{305\,K}{320\,K}$$

$$\boxed{P_2 = 146.1\,kPa}$$

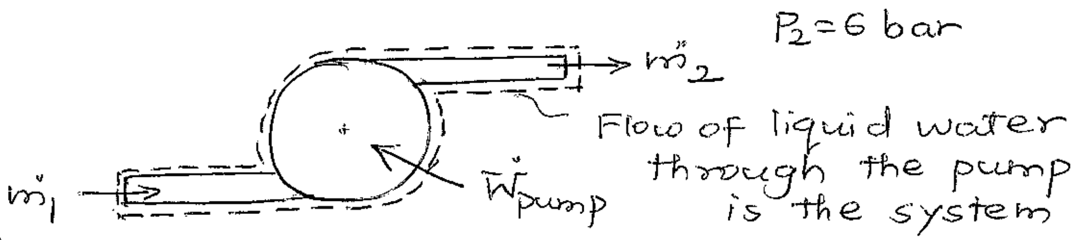
Given

An insulated liquid water pump

Find

Temperature change (°C) of liquid water

System



$P_1 = 1$ bar
$T_1 = 80°C$
$\dot{V}_1 = 0.115 \frac{m^3}{hr}$

Assumptions

- Open system
- Steady state, steady flow
- 1-D, uniform flow
- Liquid water is incompressible
- Insulated : $\dot{Q} = 0$
- Ignore change in KE and PE

Basic Equations

$$\left.\frac{dm}{dt}\right|_{system} = \sum_{in} \dot{m}_{in} - \sum_{out} \dot{m}_{out}$$

$$\left.\frac{dE}{dt}\right|_{system} = \sum_{in} \dot{m}_{in}(h + \cancel{ke} + \cancel{pe})_{in} - \sum_{out} \dot{m}_{out}(h + \cancel{ke} + \cancel{pe})_{out} + \cancel{\dot{Q}} - \dot{W}$$

0

Solution

Mass balance : $0 = \dot{m}_1 - \dot{m}_2 \Rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m}$

Energy balance: $0 = \dot{m}_1 h_1 - \dot{m}_2 h_2 - \dot{W}_{pump}$

Power for the pump : $\dot{W}_{pump} = \dot{m}(h_1 - h_2)$

Mass flow rate of liquid water : $\dot{m} = \dot{m}_1 = \frac{\dot{V}_1}{v_1}$

State 1 $\quad P_1 = 1$ bar, $T_1 = 80°C$

$T_1 < T_{sat}(P_1) \Rightarrow$ compressed (sub-cooled) liquid

$v_1 \cong v_f(T_1) = 0.0010291 \frac{m^3}{kg}$

$$\dot{m} = \frac{0.115 \frac{m^3}{hr}}{0.0010291 \frac{m^3}{kg}} = 111.75 \frac{kg}{hr} = 0.031 \frac{kg}{s}$$

$$h_1 - h_2 = \frac{\dot{W}_{pump}}{\dot{m}} = \frac{-20\ \frac{J}{s}}{0.0310\ \frac{kg}{s}} = -645.2\ \frac{J}{kg}$$

$$h_2 - h_1 = 0.645\ \frac{kJ}{kg}$$

$$h = u + Pv \Rightarrow dh = du + P\cancel{dv}^{0} + v\,dP$$
(incompressible)

$$(h_2 - h_1) = (u_2 - u_1) + (v_1 \cong v_2)(P_2 - P_1)$$

$$(h_2 - h_1) = c_{water}(T_2 - T_1) + (v_1 \cong v_2)(P_2 - P_1)$$

Temperature change of liquid water:

$$T_2 - T_1 = \frac{(h_2 - h_1) - (v_1 \cong v_2)(P_2 - P_1)}{c_{water}}$$

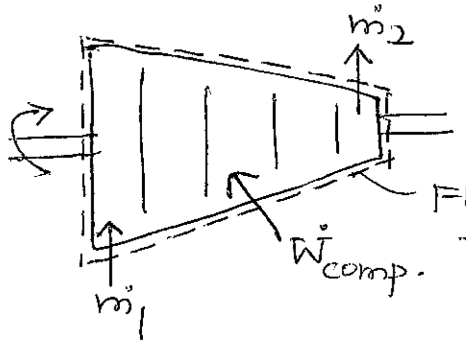
$$= \frac{0.645\ \frac{\cancel{kJ}}{\cancel{kg}} - 0.0010291\ \frac{\cancel{m^3}}{\cancel{kg}} * (6-1)\times 100\ \cancel{kPa}}{4.18\ \frac{\cancel{kJ}}{\cancel{kg}-K}}$$

$$\boxed{T_2 - T_1 = 0.0313^{\circ}C}$$

Given
An insulated nitrogen compressor

Find
Power (kW) for the compressor

System



$P_2 = 4$ bar
$T_2 = 87°C$
$\forall_2 = 25 \frac{m}{s}$

Flow of nitrogen through the compressor is the system

$P_1 = 1$ bar
$T_1 = 12°C$
$\forall_1 = 10 \frac{m}{s}$
$A_1 = 0.018 \ m^2$

Assumptions
- Open system
- Steady state, steady flow
- 1-D, uniform flow
- Nitrogen behaves as an ideal gas
- Insulated: $\dot{Q} = 0$
- Ignore PE change

Basic Equations

$$\underbrace{\frac{dm}{dt}\Big|_{system}}_{0} = \sum_{in} \dot{m}_{in} - \sum_{out} \dot{m}_{out}$$

$$\underbrace{\frac{dE}{dt}\Big|_{system}}_{0} = \sum_{in} \dot{m}_{in}(h + ke + \cancel{pe})_{in} - \sum_{out} \dot{m}_{out}(h + ke + \cancel{pe})_{out} + \cancel{\dot{Q}} - \dot{W}$$

Solution

Mass balance: $0 = \dot{m}_1 - \dot{m}_2 \Rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m}$

Energy balance: $0 = \dot{m}_1 \left(h_1 + \frac{\forall_1^2}{2}\right) - \dot{m}_2 \left(h_2 + \frac{\forall_2^2}{2}\right) + 0 - \dot{W}_{comp.}$

Power of the compressor: $\dot{W}_{comp.} = \dot{m}\left[(h_1 - h_2) + \left(\frac{\forall_1^2 - \forall_2^2}{2}\right)\right]$

Mass flow rate of nitrogen: $\dot{m} = \dot{m}_1 = \rho_1 A_1 \forall_1 = \frac{A_1 \forall_1}{v_1}$

Ideal gas equation: $P_1 v_1 = R_{N_2} T_1$

$$R_{N_2} = \frac{\bar{R}}{M_{N_2}} = \frac{8.314 \frac{kJ}{kmol-K}}{28.01 \frac{kg}{kmol}} = 0.297 \frac{kJ}{kg-K}$$

$$v_1 = \frac{R_{N_2} T_1}{P_1} = \frac{0.297 \frac{kJ}{kg-K} * (12 + 273) K}{(1 \times 100) \ kPa} = 0.8465 \frac{m^3}{kg}$$

$$\dot{m} = \frac{0.018\ \cancel{m^2} * 10\ \frac{\cancel{m}}{s}}{0.8465\ \frac{\cancel{m^3}}{kg}} = 0.213\ \frac{kg}{s}$$

State 1 $\quad T_1 = 12^\circ c = 285\ K\ ,\ \bar{h}_1 = 8272\ \frac{kJ}{kmol}$

$$h_1 = \frac{\bar{h}_1}{M_{N_2}} = \frac{8272\ \frac{kJ}{kmol}}{28.01\ \frac{kg}{kmol}} = 295.3\ \frac{kJ}{kg}$$

State 2 $\quad T_2 = 87^\circ c = 360\ K\ ,\ \bar{h}_2 = 10457\ \frac{kJ}{kmol}$

$$h_2 = \frac{\bar{h}_2}{M_{N_2}} = \frac{10457\ \frac{kJ}{kmol}}{28.01\ \frac{kg}{kmol}} = 373.3\ \frac{kJ}{kg}$$

$$\dot{W}_{comp.} = 0.213\ \frac{kg}{s} * \left[(295.3 - 373.3)\ \frac{kJ}{kg} + \frac{(10)^2 - (25)^2}{2*1000}\ \frac{kJ}{kg} \right]$$

$$\boxed{\dot{W}_{comp.} = -16.7\ kW}$$ $\dot{W} < 0$ power input

Given

Flow through a throttling valve operating at steady state

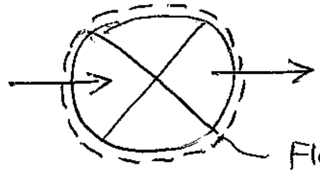
Find

(a) Temperature (°C) of air at the exit

(b) Temperature (°C) of R-134a at the exit

System

$P_1 = 10$ bar, $T_1 = 20°C$ $\quad \dot{m}_1 \rightarrow$



$\rightarrow \dot{m}_2 \quad P_2 = 1$ bar

Flow through the throttling valve is the system

Assumptions

- Open system
- Steady state, steady flow
- 1-D, uniform flow
- Ignore change in KE and PE
- Insulated : $\dot{Q} = 0$
- Passive : $\dot{W} = 0$
- Air behaves as an ideal gas

Basic Equations

$$\cancel{\frac{dm}{dt}}\bigg|_{system}^{0} = \sum_{in} \dot{m}_{in} - \sum_{out} \dot{m}_{out}$$

$$\cancel{\frac{dE}{dt}}\bigg|_{system}^{0} = \cancel{\dot{Q}}^{0} - \cancel{\dot{W}}^{0} + \sum_{in} \dot{m}_{in}(h + \cancel{ke} + \cancel{pe})_{in} - \sum_{out} \dot{m}_{out}(h + \cancel{ke} + \cancel{pe})_{out}$$

Solution

Mass balance : $0 = \dot{m}_1 - \dot{m}_2 \Rightarrow \dot{m}_1 = \dot{m}_2$

Energy balance : $0 = 0 - 0 + \cancel{\dot{m}_1} h_1 - \cancel{\dot{m}_2} h_2 \Rightarrow h_1 = h_2$

(a) Air as the working fluid

State 1 $\quad P_1 = 10$ bar, $T_1 = 20°C = 293.15$ K

$$h_1 = 293.25 \ \frac{kJ}{kg}$$

State 2 $\quad P_2 = 1$ bar, $h_2 = 293.25 \ \frac{kJ}{kg}$

$$T_2 = 293.15 \text{ K} \Rightarrow \boxed{T_2 = 20°C}$$

$\because h = f(T)$ only for an ideal gas

(b) R-134a as the working fluid

State 1 $P_1 = 10$ bar, $T_1 = 20°C$

$T_1 < T_{sat}(P_1) \Rightarrow$ sub-cooled (compressed) liquid

$$h_1 \cong h_f(T_1) + v_f(T_1)\,(P_1 - P_{sat}(T_1))$$

$$= 79.324\ \frac{kJ}{kg} + 0.00081610\ \frac{m^3}{kg} * (10 - 5.7171) \times 100\ kPa$$

$$= 79.674\ \frac{kJ}{kg}$$

State 2 $P_2 = 1$ bar, $h_2 = 79.674\ \frac{kJ}{kg}$

$h_f(P_2) < h_2 < h_g(P_2) \Rightarrow$ saturated liquid-vapor mixture

$$\Rightarrow T_2 = T_{sat}(P_2)$$

$$\boxed{T_2 = -26.361°C}$$

Given

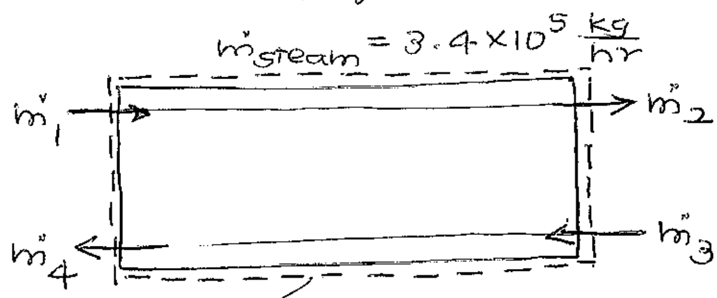
Condenser in a thermal power plant

Find

Mass flow rate $\left(\frac{kg}{hr}\right)$ of cooling water

System

$P_1 = 0.08$ bar
$x_1 = 0.932$



$P_2 = 0.08$ bar
sat. liquid

$P_4 = 1$ bar
$T_4 = 35°C$

$P_3 = 1$ bar
$T_3 = 15°C$

Flow of steam and cooling water through the condenser is the system

Assumptions

- Open system
- Steady state, steady flow
- 1-D, uniform flow
- Ignore change in KE and PE
- Insulated (overall) : $\dot{Q} = 0$
- Passive : $\dot{W} = 0$

Basic Equations

$$\left.\frac{dm}{dt}\right|_{system} = \sum_{in} \dot{m}_{in} - \sum_{out} \dot{m}_{out}$$

$$\cancel{\left.\frac{dE}{dt}\right|_{system}}^{\,0} = \sum_{in} \dot{m}_{in}(h + \cancel{ke} + \cancel{pe})_{in} - \sum_{out} \dot{m}_{out}(h + \cancel{ke} + \cancel{pe})_{out} + \cancel{\dot{Q}} - \cancel{\dot{W}}$$

Solution

Mass balance : $0 = \dot{m}_1 - \dot{m}_2 \Rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m}_{steam}$

$0 = \dot{m}_3 - \dot{m}_4 \Rightarrow \dot{m}_3 = \dot{m}_4 = \dot{m}_{cooling\ water}$

Energy balance : $0 = (\dot{m}_1 h_1 + \dot{m}_3 h_3) - (\dot{m}_2 h_2 + \dot{m}_4 h_4) + 0 - 0$

$$\dot{m}_{cooling\ water}(h_4 - h_3) = \dot{m}_{steam}(h_1 - h_2)$$

Mass flow rate of cooling water :

$$\dot{m}_{cooling\ water} = \frac{\dot{m}_{steam}(h_1 - h_2)}{(h_4 - h_3)}$$

State 1 $P_1 = 0.08$ bar, $x_1 = 0.932$

$$h_1 = h_f(P_1) + x_1 (h_g(P_1) - h_f(P_1))$$
$$= 173.84 \frac{kJ}{kg} + 0.932 * (2576.2 - 173.84) \frac{kJ}{kg}$$
$$= 2412.8 \frac{kJ}{kg}$$

State 2 $P_2 = 0.08$ bar, sat. liquid

$$h_2 = h_f(P_2) = 173.84 \frac{kJ}{kg}$$

State 3 $P_3 = 1$ bar, $T_3 = 15°C$

$T_3 < T_{sat}(P_3) \Rightarrow$ compressed (sub-cooled) liquid

$$h_3 \cong h_f(T_3) + v_f(T_3)(P_3 - P_{sat}(T_3))$$
$$= 62.981 \frac{kJ}{kg} + 0.0010009 \frac{m^3}{kg} * (1 - 0.017058) \times 100 \text{ kPa}$$
$$= 63.08 \frac{kJ}{kg}$$

State 4 $P_4 = 1$ bar, $T_4 = 35°C$

$T_4 < T_{sat}(P_4) \Rightarrow$ compressed (sub-cooled) liquid

$$h_4 \cong h_f(T_4) + v_f(T_4)(P_4 - P_{sat}(T_4))$$
$$= 146.63 \frac{kJ}{kg} + 0.00100060 \frac{m^3}{kg} * (1 - 0.056290) \times 100 \text{ kPa}$$
$$= 146.73 \frac{kJ}{kg}$$

$$\dot{m}_{\substack{cooling \\ water}} = \frac{3.4 \times 10^5 \frac{kg}{hr} * (2412.8 - 173.84) \frac{kJ}{kg}}{(146.73 - 63.08) \frac{kJ}{kg}}$$

$$\boxed{\dot{m}_{\substack{cooling \\ water}} = 9.1 \times 10^6 \frac{kg}{hr}}$$